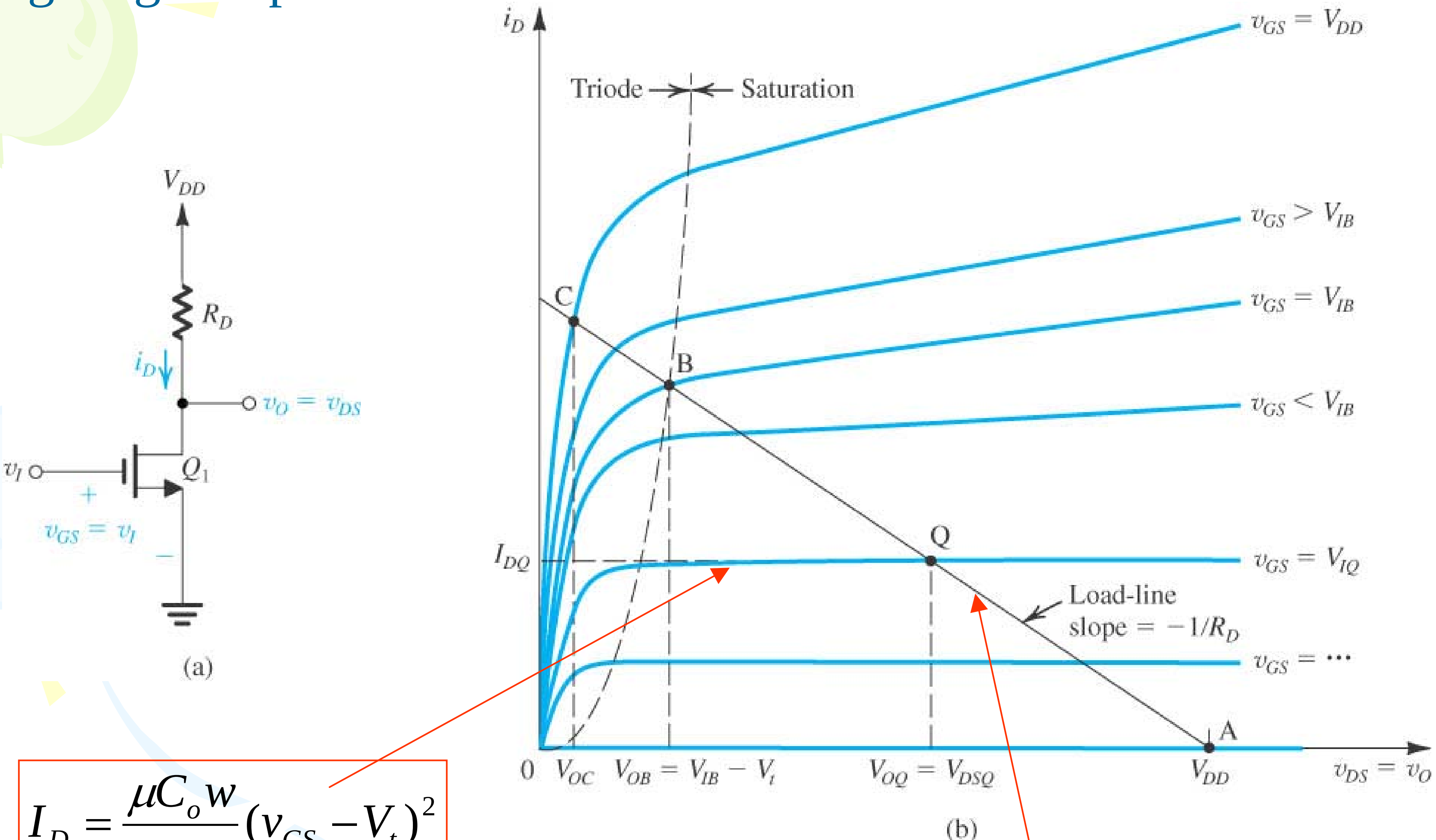
Lecture 08

MOSFET's Circuit

topics

1. Large-signal operation
2. FET circuits at DC
3. FET biasing schemes

Large-signal operation

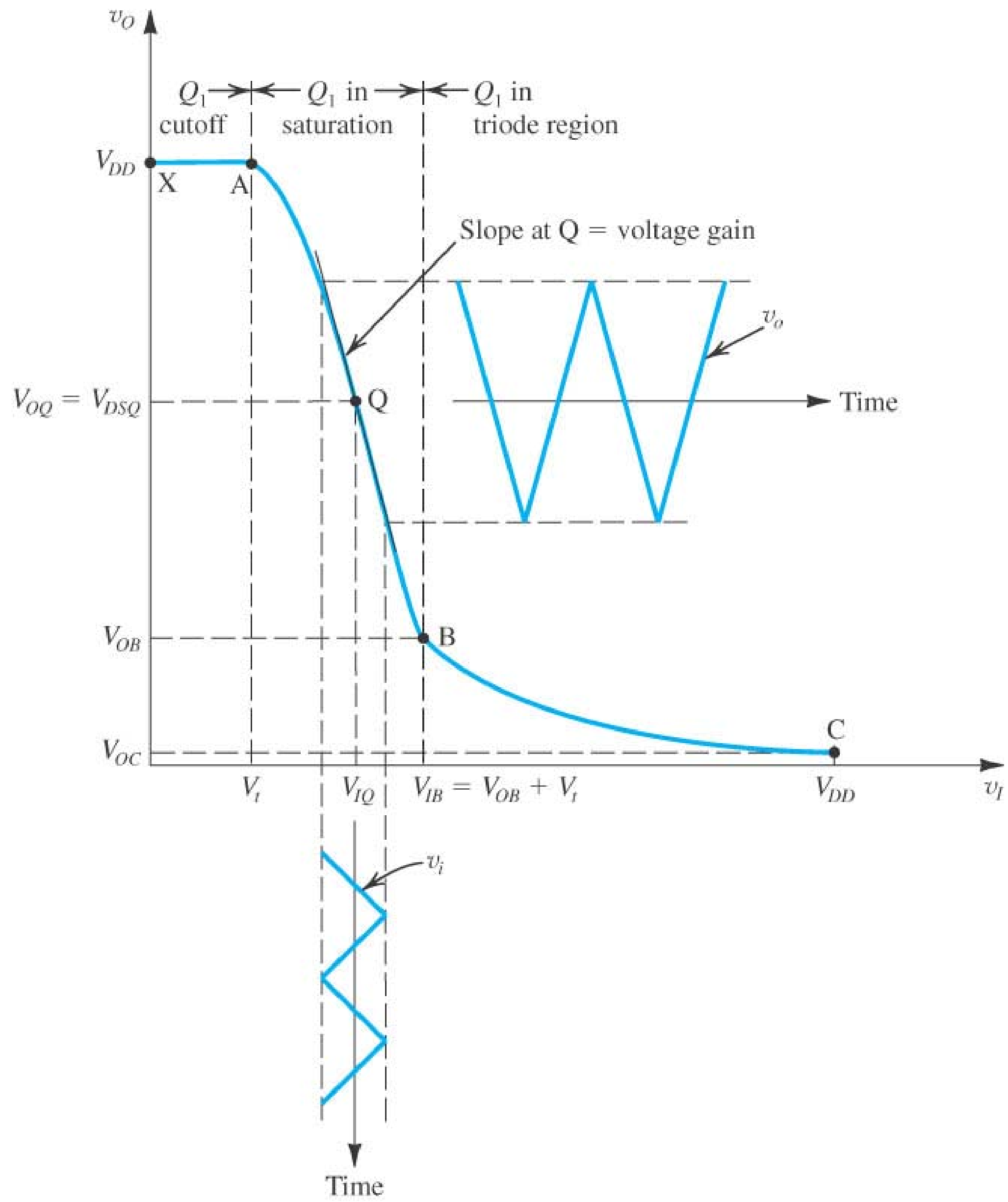


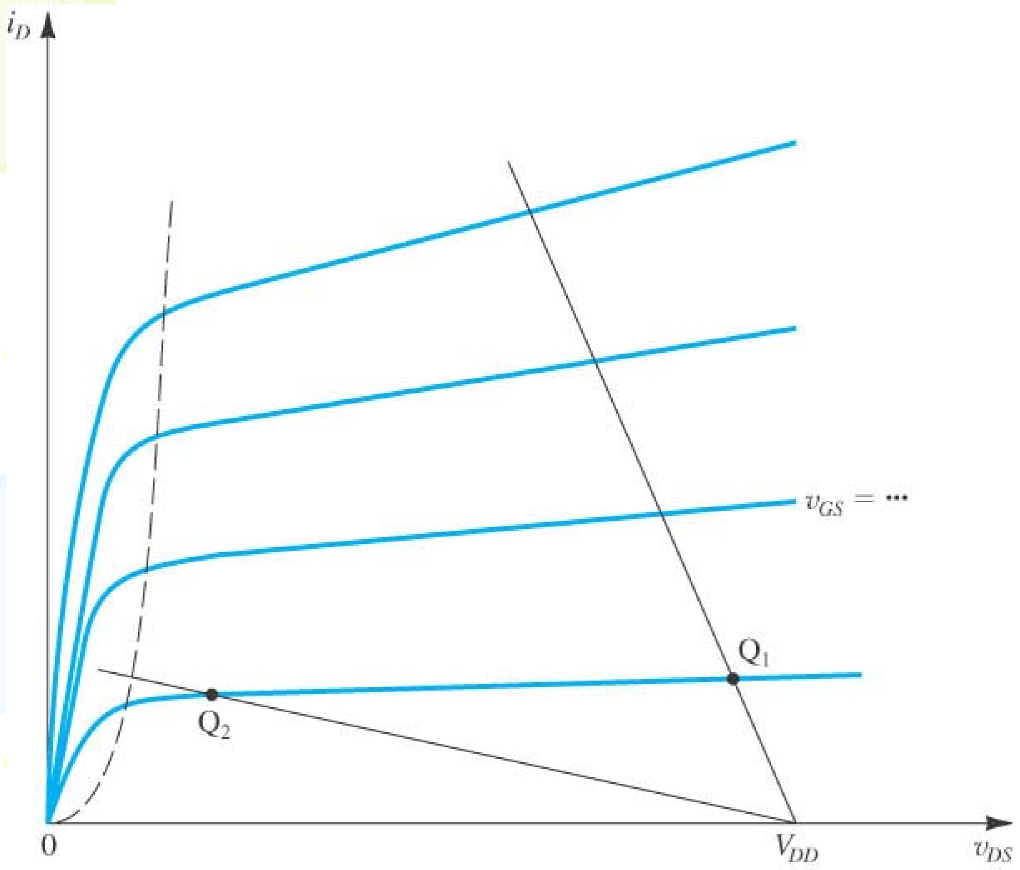
$$\boxed{I_D = \frac{\mu C_o w}{2L}(v_{GS} - V_t)^2}$$

$$\boxed{I_D = \frac{k_n' w}{2L}(v_{GS} - V_t)^2}$$

Load line: $\boxed{V_{DD} = i_D R_D + v_{DS}}$

$$A_v \equiv \left.\frac{dv_o}{dv_I}\right|_{v_I = V_{IQ}}$$



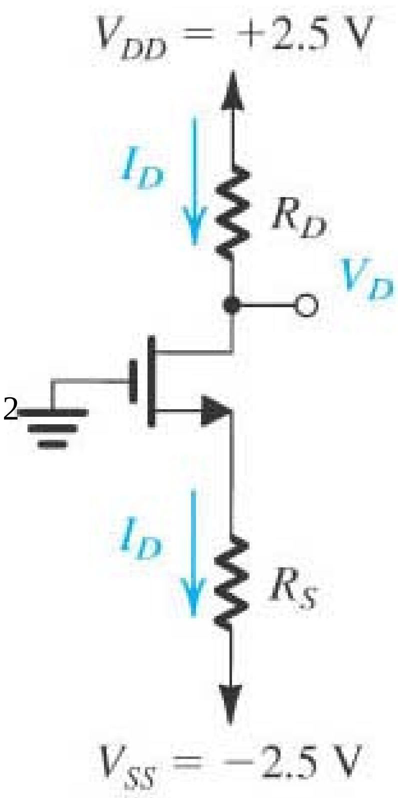


i_D
$v_{GS} = \cdots$
Q_1
Q_2
0
V_{DD}
v_{DS}

DC analysis

Example 4.2

Given
$$I_D = 0.4mA$$
$$V_D = 0.5V$$
$$V_t = 0.7V$$
$$\mu_n C_{ox} = 100\mu A/V^2$$
$$L = 1\mu m$$
$$w = 32\mu m$$
$$R_D = ?$$
$$R_S = ?$$



$$I_D = \frac{\mu C_o w}{2L}(v_{GS} - V_t)^2$$
$$\Rightarrow v_{GS} = 1.2V$$

$$V_S = I_D R_S + V_{SS}$$
$$\Rightarrow V_S = I_D R_S - 2.5V$$
$$R_s = \frac{-1.2 + 2.5}{0.4m} = 3.25k$$

$$V_{DD} = I_D R_D + V_D$$
$$\Rightarrow 2.5V = I_D R_D + V_D$$
$$R_D = \frac{2.5 - 0.5}{0.4m} = 5k$$

Example 4.3

Given

$$I_D = 80\mu A$$

$$V_t = 0.6V$$

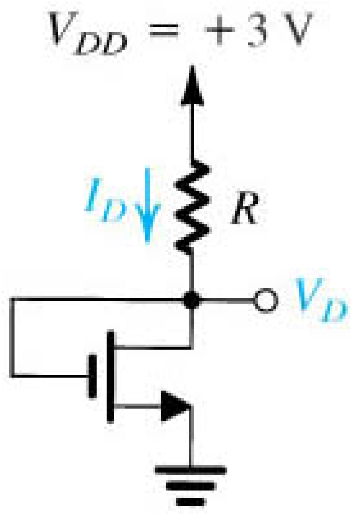
$$\mu_n C_{ox} = 200\mu A/V^2$$

$$L = 0.8\mu m$$

$$w = 4\mu m$$

$$V_D = ?$$

$$R = ?$$



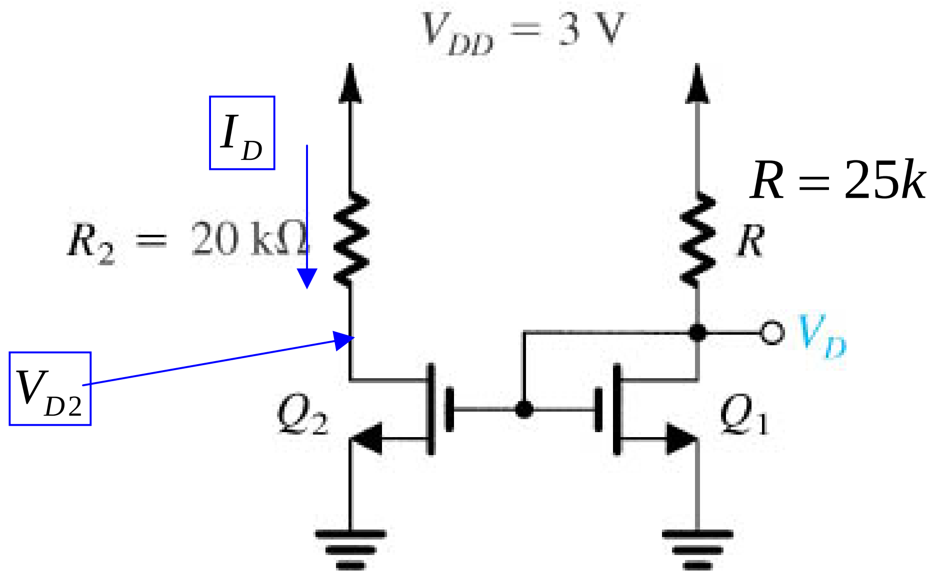
$$I_D = \frac{\mu C_o w}{2L}(V_D - V_t)^2$$

$$\Rightarrow V_D = 1V$$

$$V_{DD} = 3V = I_D R + V_D$$

$$\Rightarrow R = \frac{3-1}{0.08m} = 25k$$

Exercise 4.12



$$I_D = \frac{\mu C_o w}{2L}(V_{GS2} - V_t)^2 = \frac{\mu C_o w}{2L}(V_D - V_t)^2$$

$$\because V_D = 1V \therefore I_D = 80\mu A$$

$$V_{DD} = 3V = I_D R_2 + V_{D2}$$

$$\Rightarrow V_{D2} = 3 - 80\mu \times 20k = 1.4V$$

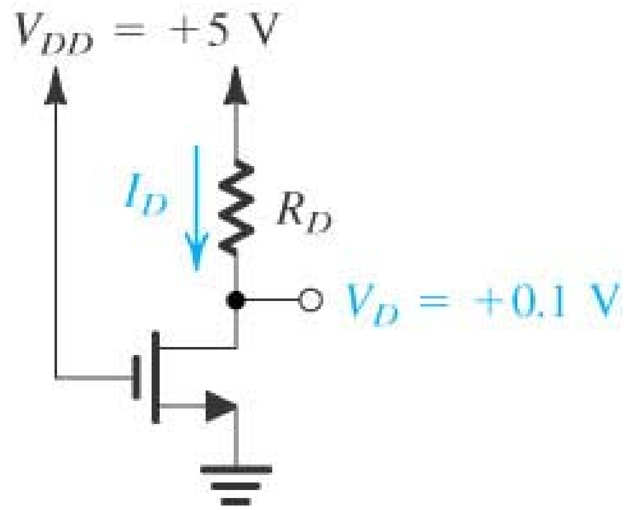
Example 4.4

$$let$$

$$V_t = 1V$$

$$K_n'(W/L) = 1mA/V^2$$

$$find \quad R_D = ?$$



$$v_{DS} = V_D = 0.1V \le V_{DD} - V_t = 5 - 1 = 4$$

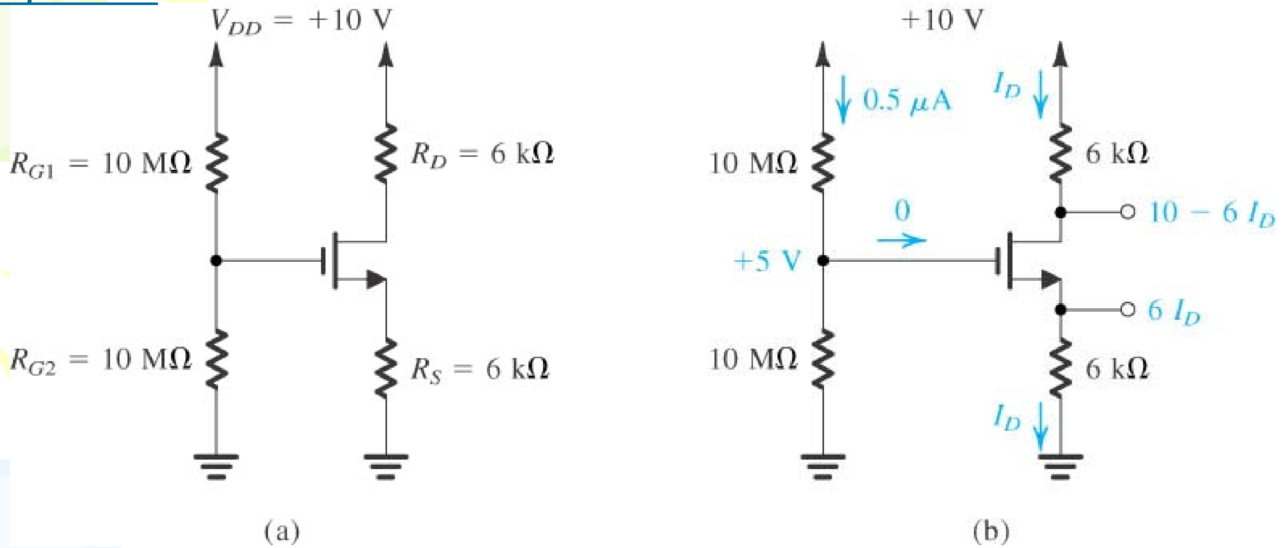
$$v_{DS} \le v_{GS} - V_t \rightarrow ohmic \quad region$$

$$I_D = \frac{\mu_n C_o w}{2L}[2(v_{GS} - V_t)v_{DS} - v_{DS}^2]$$

$$\rightarrow I_D = 0.395mA$$

$$R_D = \frac{5 - 0.1}{0.395m} = 12.4k$$

Example 4.5



$$let$$
$$V_t = 1V$$
$$K_n'(W/L) = 1mA/V^2$$

Assume FET in saturation mode since V_G>0

$$V_G = \frac{10M}{10M + 10M}10V = 5V$$

$$I_D = \frac{1}{2}k_n' \frac{W}{L}(V_{GS} - V_t)^2$$

$$\Rightarrow I_D = \frac{1}{2} \times 1 \times [(5 - I_D \times 6k) - 1]^2$$

$$\Rightarrow 18I_D^2 - 25I_D + 8 = 0$$

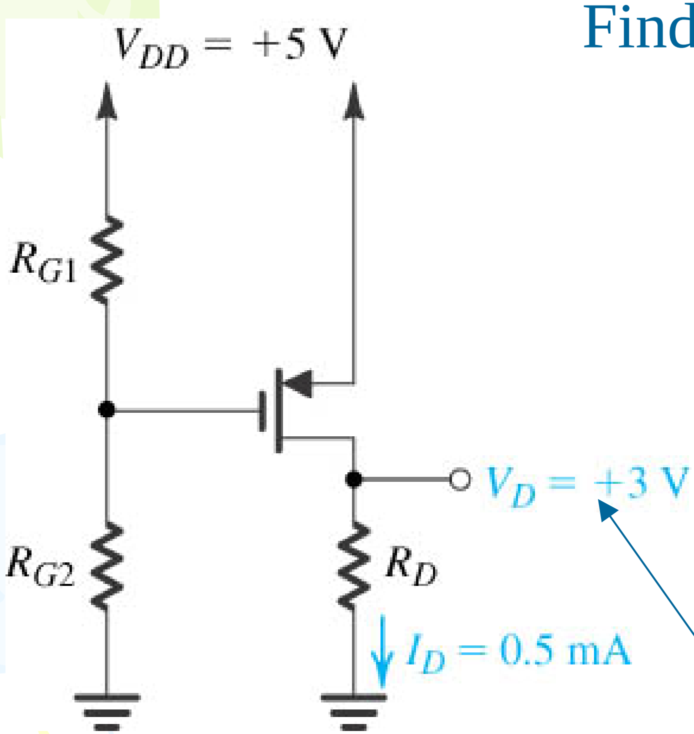
$$I_D = 0.89mA, I_D = 0.5mA$$

$$if \quad I_D = 0.89mA$$
$$V_S = 6k \times 0.89m = 5.34V$$
$$\rightarrow V_{GS} < 0$$ contradiction

$$if \quad I_D = 0.5mA$$
$$V_S = 6k \times 0.5m = 3V$$
$$\rightarrow V_{GS} = 2V$$
$$\rightarrow V_D = 10 - 6k \times 0.5m = 7V$$
$$\rightarrow V_D > V_G - V_t$$

Example 4.6

Design the circuit operate in saturation
Find the range of R_D



$$I_D = \frac{1}{2} k_n' \frac{W}{L} (V_{GS} - V_t)^2$$

$$\Rightarrow 0.5 = \frac{1}{2} \times 1 \times [V_{GS} - (-1)]^2$$

$$\Rightarrow V_{GS} = -2V$$

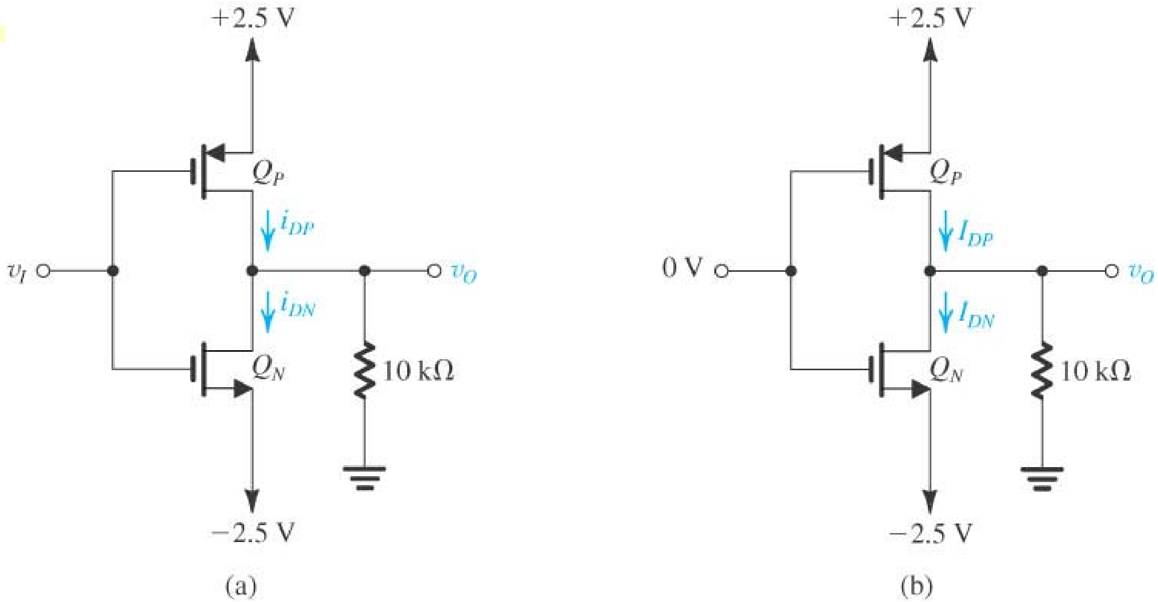
$$V_{DS} \geq V_{GS} - V_t = -2 + 1 = -1$$

$$\Rightarrow V_{D(\max)} = +4V$$

$$R_{D(\max)} = \frac{4}{0.5m} = 8k$$

$$R_{D(\min)} = \frac{3}{0.5m} = 6k$$

Example 4.7



let

$$V_{nt} = -V_{pt} = 1V$$

$$K'_n(W/L)$$

$$= K'_p(W/L) = 1mA/V^2$$

First case : v_I=0V

Q_p *on*, Q_n *on*

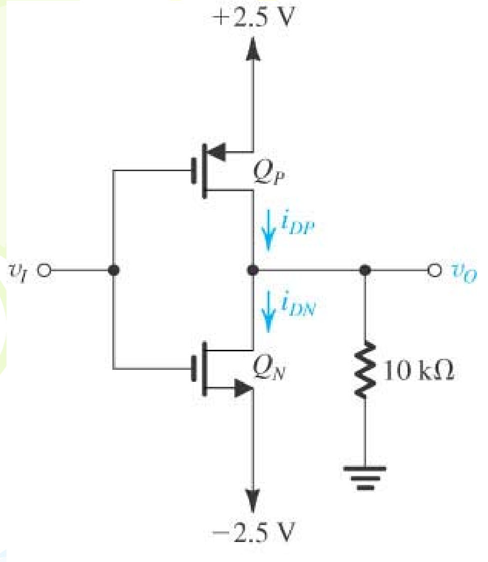
$$V_{GS(p)} = -2.5V$$

$$V_{GS(n)} = 2.5V$$

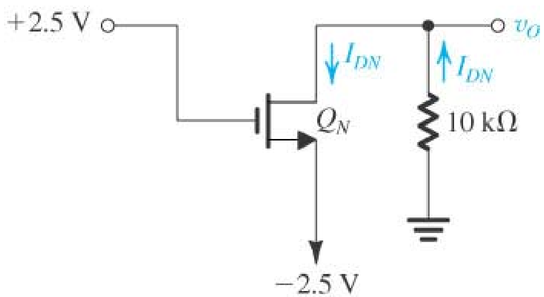
$$v_o = 0V$$

$$I_{DP} = \frac{1}{2} \times 1[-2.5-(-1)]^2 = 1.125mA$$

$$I_{Dn} = \frac{1}{2} \times 1[2.5-1]^2 = 1.125mA$$



(a)



(c)

Second case : v_I=+2.5V

$Q_p \quad off, \quad Q_n \quad ohmic \quad region$

$$\boxed{I_D = \frac{\mu_n C_o w}{2L}[2(v_{GS} - V_t)v_{DS} - v_{DS}^2] \approx \frac{\mu_n C_o w}{L}(v_{GS} - V_t)v_{DS}}$$

$$V_{GS} = 5V$$

$$I_{Dn} = 1\times1[5-1]V_{DS}$$

$$= 1\times1[5-1](-I_{Dn}\times10k)$$

$$\Rightarrow I_{Dn} = 0.244mA$$

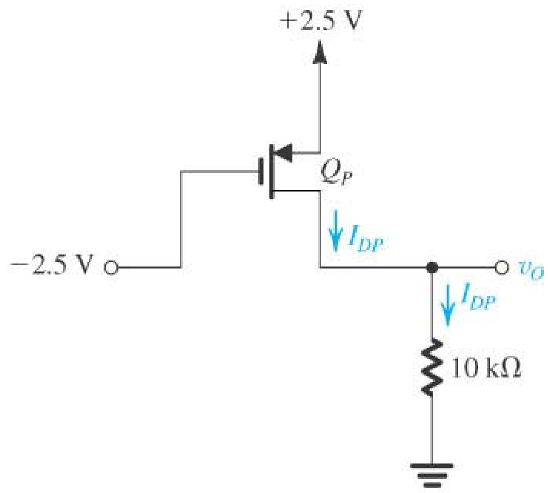
$$V_D = -2.44V = v_o$$

NOT gate

$$V_{DS} = -2.44 + 2.5 = 0.06$$

$$V_{GS} - V_t = 5 - 1 = 4$$

$V_{DS} \le V_{GS} - V_t$ Ohmic region



(d)

Second case : v_I=-2.5V

Q_p ohmic region, Q_n off

NOT gate

$$V_{SG} = 5V$$

$$I_{Dp} = 1\times1[5-1]V_{SD}$$

$$= 1\times1[5-1](2.5 - I_{Dp}\times10k)$$

$$\Rightarrow I_{Dp} = 0.244mA$$

$$V_D = v_o = I_{Dp}\times10k = 2.44V$$

$$V_{SD} = +2.5 - 2.44 = 0.06$$

$$V_{SG} - V_t = 5 - 1 = 4$$

$$V_{SD} \le V_{SG} - |V_t|$$ Ohmic region

Exercise 4.16 Amplifier

Assume

$$k_n^{'}(W_n / L_n) = k_p^{'}(W_p / L_p) = 1(mA/V^2)$$

$$V_{tn} = -V_{tp} = 1V$$

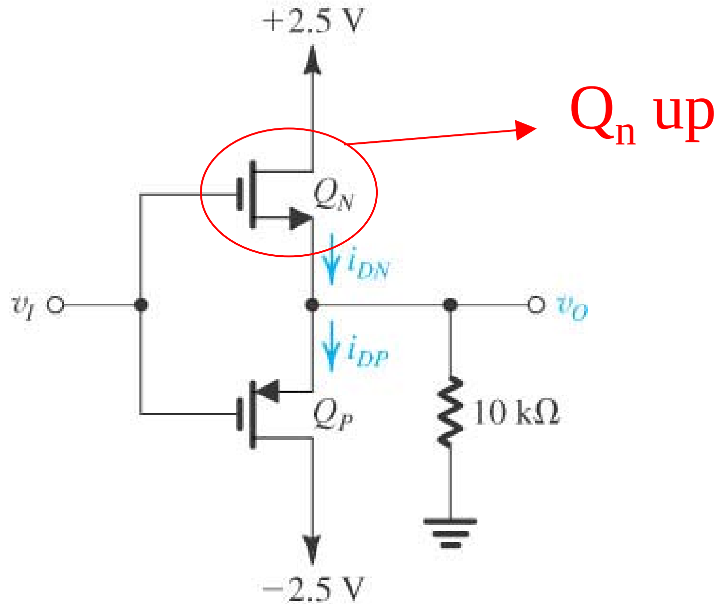
$$\lambda = 0$$

find

$$i_{DN}, \quad i_{DP}, \quad v_o$$

for

$$v_I = 0V, 2.5V, -2.5V$$



First case : v_I=0V

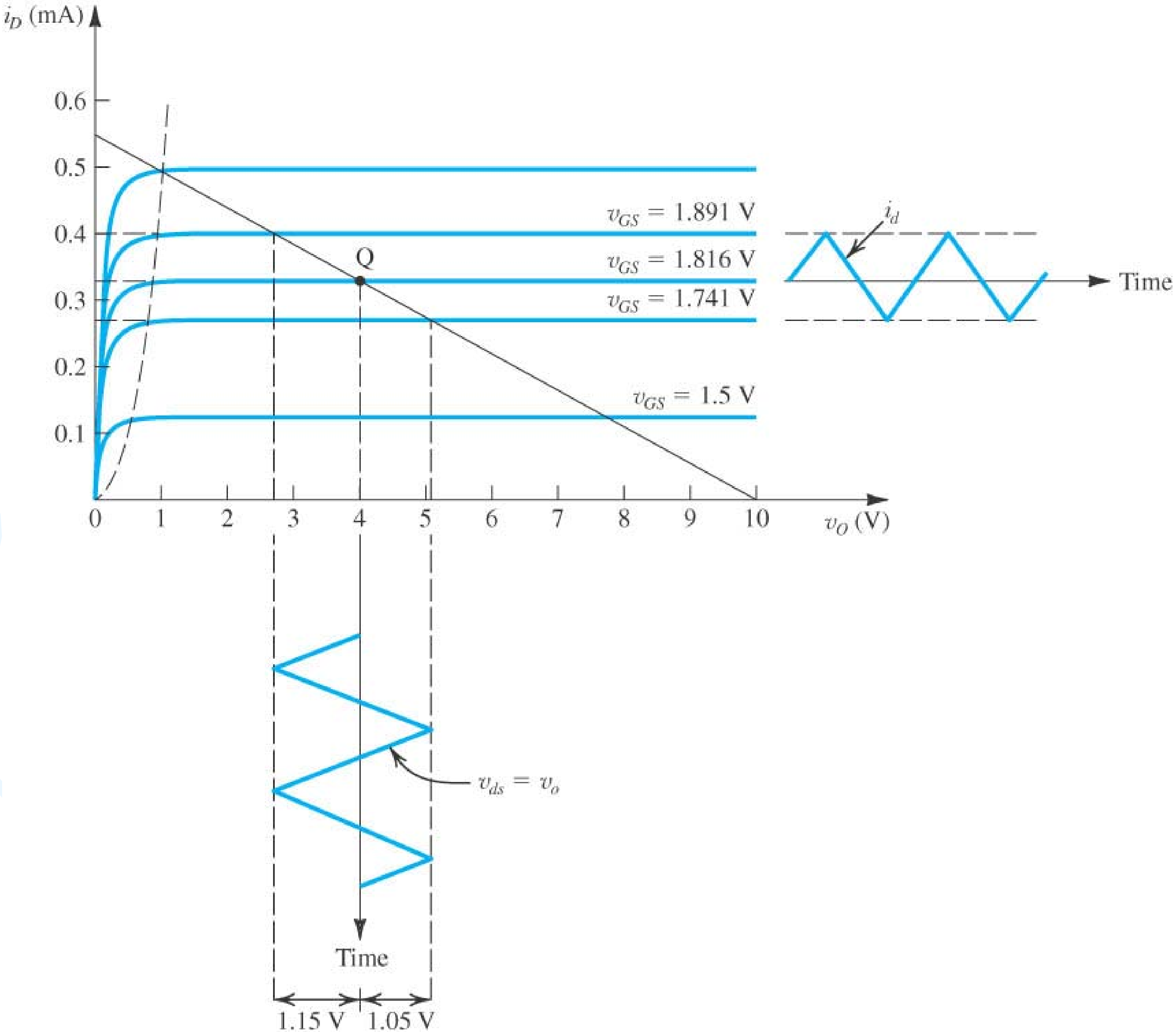
$Q_n \quad off \quad Q_p \quad off$

2nd case : v_I=2.5V

$Q_n \quad on \quad Q_p \quad off$

3rd case : v_I=2.5V

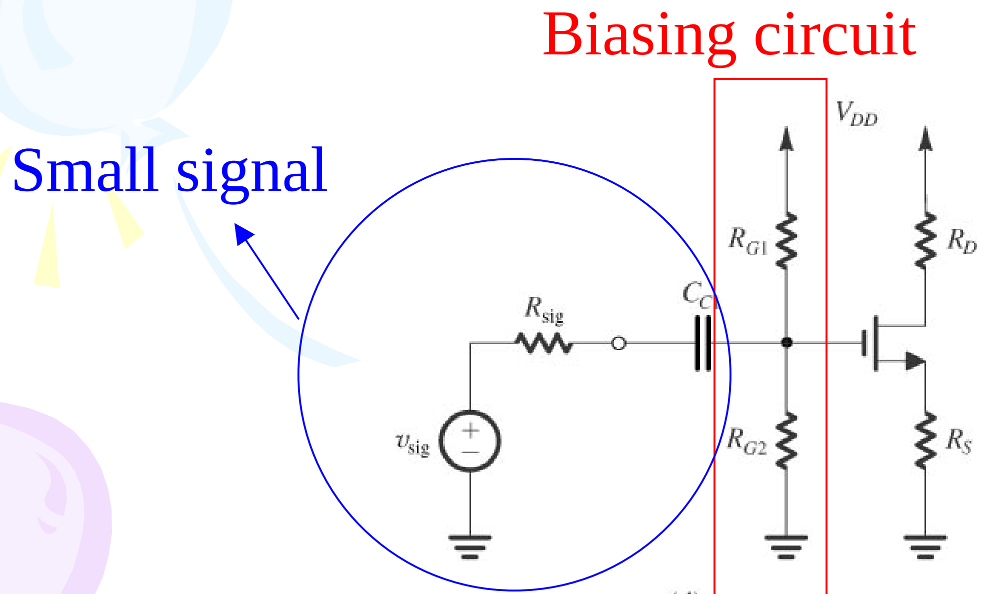
$Q_n \quad off \quad Q_p \quad on$


i_D (mA)
0.6
0.5
0.4
0.3
0.2
0.1
0
1
2
3
4
5
6
7
8
9
10
v_O (V)
Q
$v_{GS} = 1.891$ V
$v_{GS} = 1.816$ V
$v_{GS} = 1.741$ V
$v_{GS} = 1.5$ V
i_d
Time
$v_{ds} = v_o$
Time
1.15 V
1.05 V

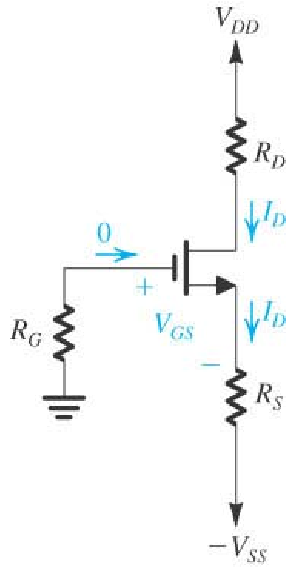
(b)

Biasing method

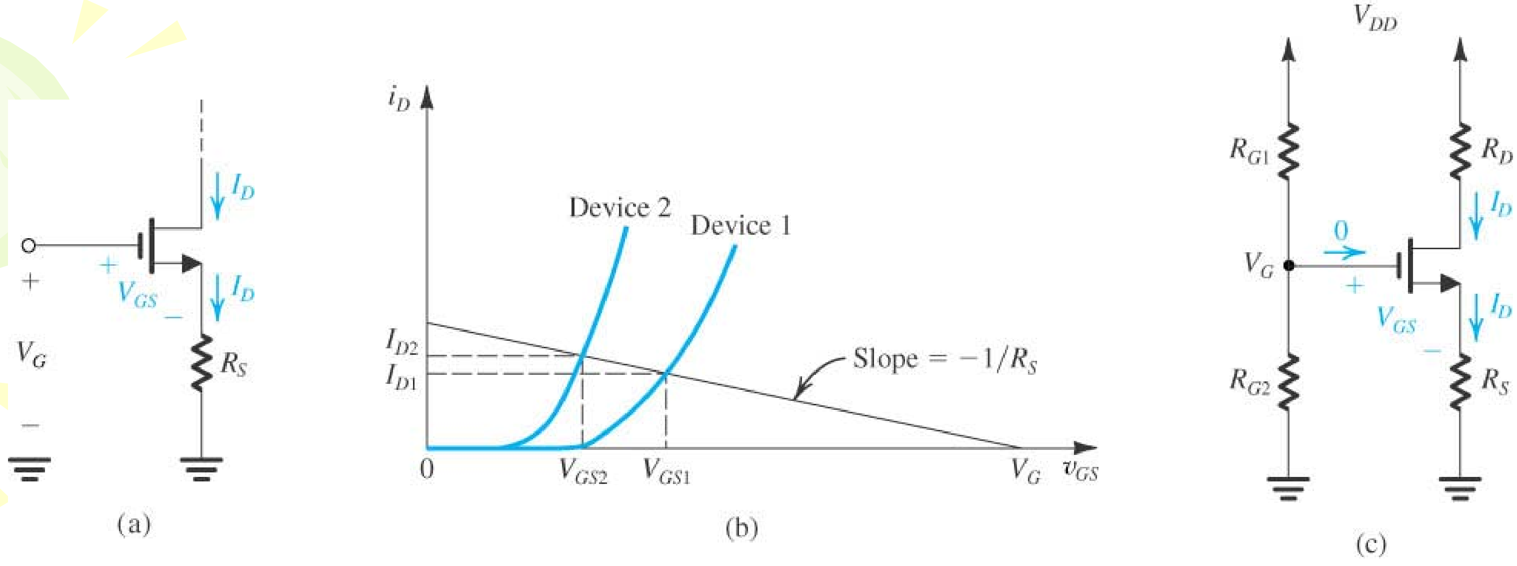
- Fixed Bias by V_{GS}
- Self Bias
- Biasing using Drain –to-Gate feedback resistor
- Biasing using constant current source



(d)



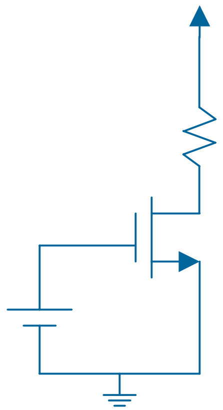
(e)



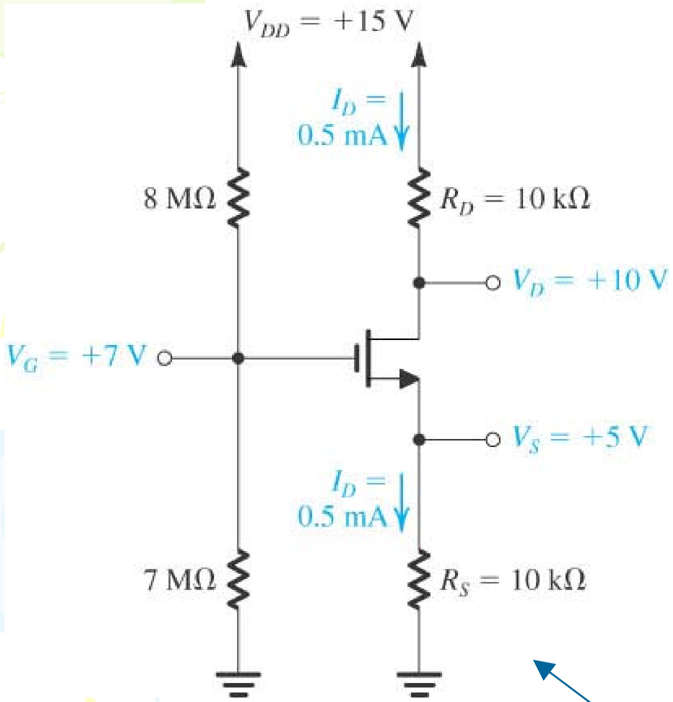
$$\boxed{I_D = \frac{\mu_n C_o w}{2L}(v_{GS} - V_t)^2}$$

1. Device change ($V_t, C_{ox}, W/L$)
2. Temperature change (V_t, μ_n)

Change I_D



Example 4.9 Fixed Bias



when

$$V_t = 1V$$

$$K_n'(W/L) = 1mA/V^2$$

$$I_D = 0.5mA$$

find

$V_t = 1.5V$ Change MOSFET

$$K_n'(W/L) = 1mA/V^2$$

$$\Delta I_D = ?\,mA$$

$$I_D = \frac{k_n' w}{2L}(v_{GS} - V_t)^2 = \frac{1}{2} \times 1 \times (v_{GS} - 1.5)^2$$

$$v_{GS} = 7 - 10k \times I_D$$

$$\Rightarrow I_D = 0.455mA$$

Good biasing scheme

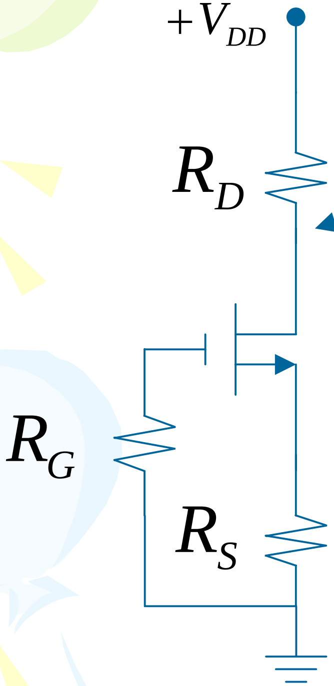
$$I_D \uparrow \Rightarrow I_D R_S \uparrow \Rightarrow \because V_G\ fixed \Rightarrow V_{GS} \downarrow$$

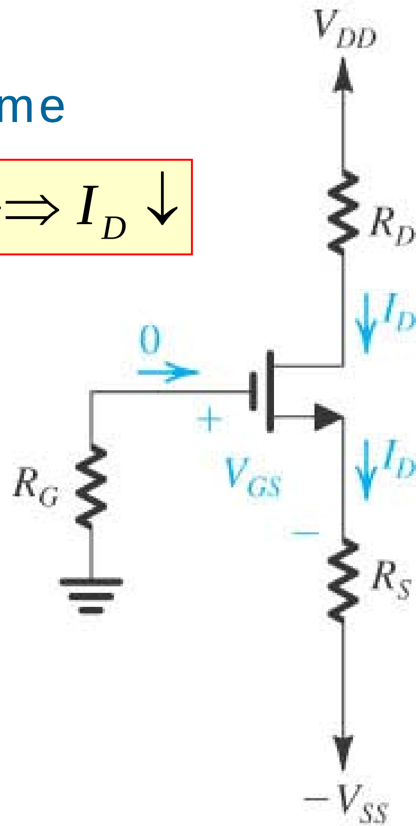
$$\because I_D = \frac{k_n' W}{2L}(v_{GS} \downarrow - V_t)^2 \Rightarrow I_D \downarrow$$

Self Bias

Good biasing scheme

$$I_D \uparrow (I_G = 0) \Rightarrow V_{GS} \downarrow \Rightarrow I_D \downarrow$$





(e)

$$I_D = \frac{k_n^{'} w}{2L}(v_{GS} - V_t)^2$$

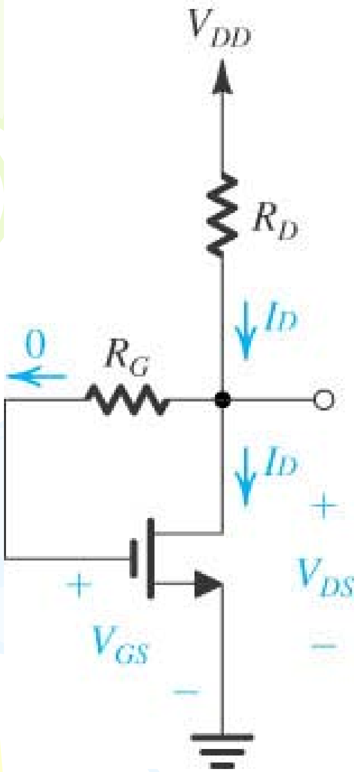
$$V_{GS} = -I_D R_S$$

$$I_D \uparrow \Rightarrow V_S \uparrow \Rightarrow V_{GS} \downarrow \Rightarrow I_D \downarrow$$

Good biasing scheme

Exercise 4.21

Drain –to-Gate feedback bias



parameters

$$V_{DD} = 5V$$

$$V_t = 1V$$

$$K_n'(W/L) = 1mA/V^2$$

requirement

$$I_D = 0.5mA$$

find

$$R_D, V_D$$

$$I_D = \frac{k_n' w}{2L}(V_{GS} - V_t)^2$$

$$0.5m = \frac{1}{2} \times 1 \times (V_{GS} - 1)^2$$

$$\Rightarrow V_{GS} = 2V$$

$$V_{GS} = V_{DS} = V_{DD} - I_D R_D$$

$$V_{GS} = V_{DS} = 5 - I_D \times R_D$$

$$2V = 5 - 0.5 \times R_D$$

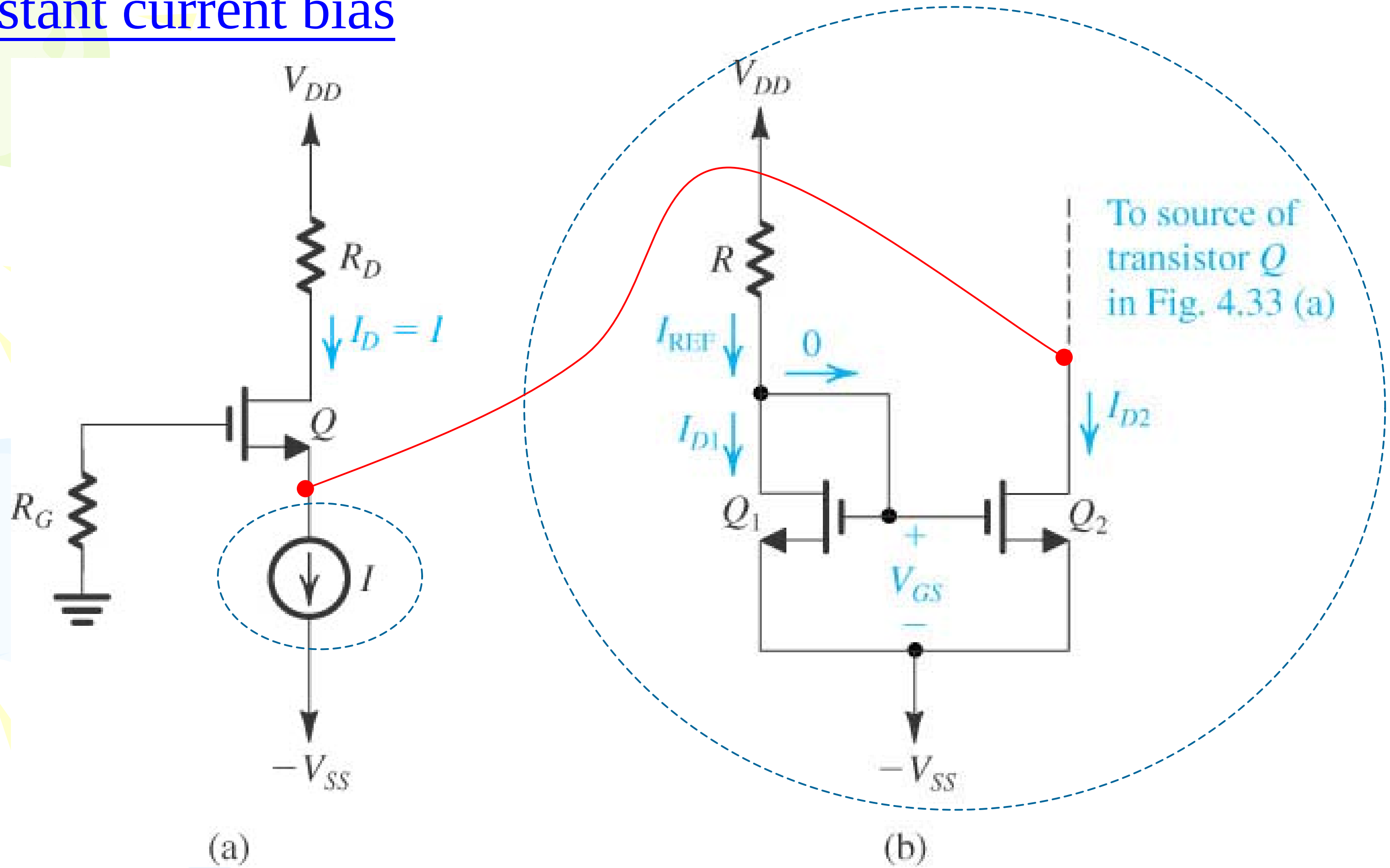
$$\Rightarrow R_D = 6k$$

$$V_{GS} = V_{DS} \Rightarrow saturation$$

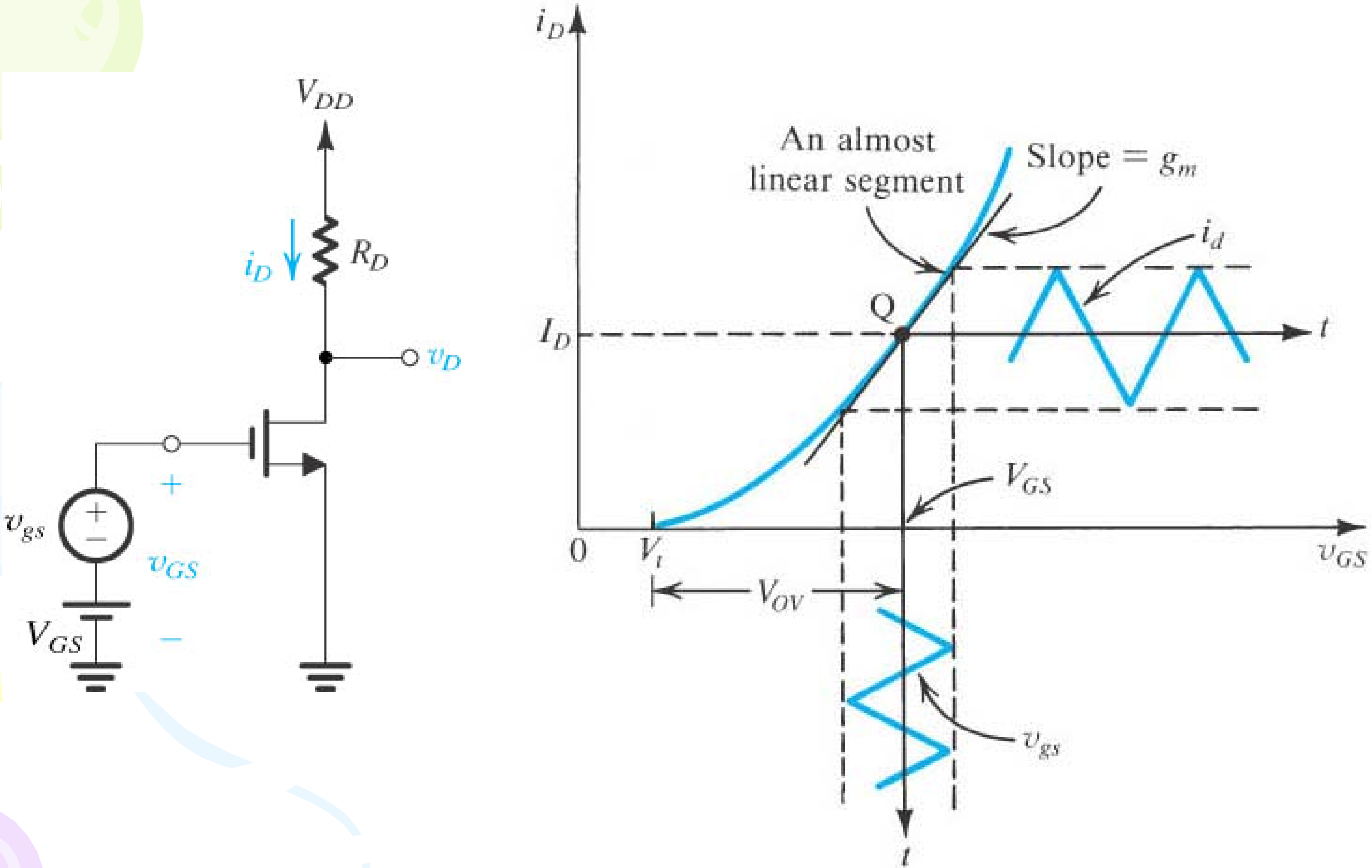
$$\boxed{\begin{aligned} & I_D \uparrow \Rightarrow V_D = V_{DD} - I_D R_D \Rightarrow V_D \downarrow \\ & \Rightarrow V_{GS} \Rightarrow I_D \downarrow \end{aligned}}$$

Good biasing scheme

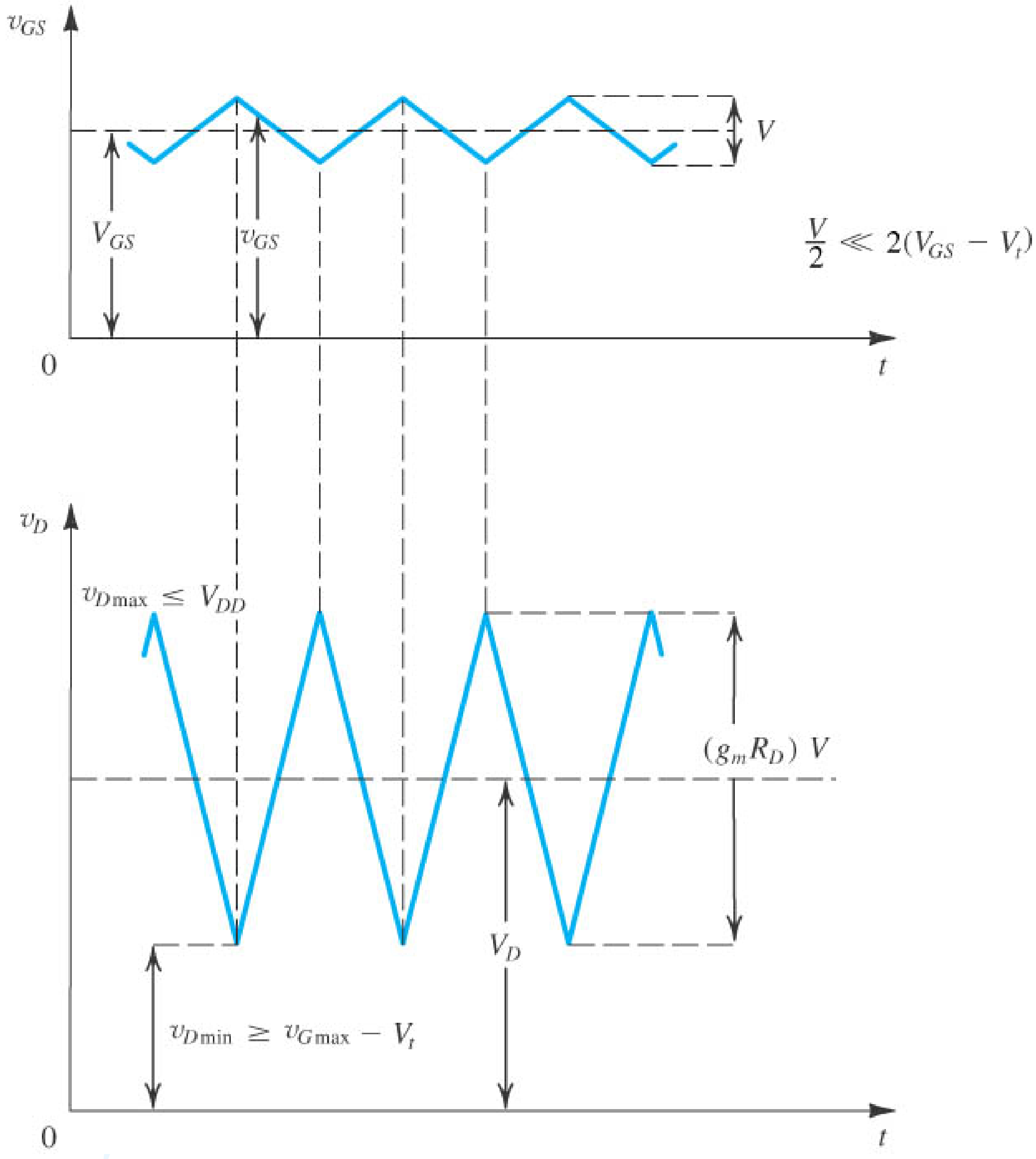
Constant current bias



$$I_{REF} = I_{D1} = \frac{V_{DD} - V_{GS}}{R} = I_{D2}$$



V_{DD}
i_D
R_D
v_D
v_{gs}
+
v_{GS}
−
V_{GS}
i_D
An almost
linear segment
Slope = g_m
i_d
Q
I_D
t
V_{GS}
0
V_t
v_{GS}
V_{OV}
v_{gs}
t


v_{GS}
V
V_{GS}
v_{GS}
$\frac{V}{2} \ll 2(V_{GS} - V_t)$
0
t
v_D
$v_{D\max} \leq V_{DD}$
$(g_m R_D)\ V$
V_D
$v_{D\min} \geq v_{G\max} - V_t$
0
t